AD-A016 017

DUCT FLOW ANALYSIS METHODS FOR V/STOL PROPULSION SYSTEM APPLICATIONS

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Prepared for:

Naval Air Systems Command

December 1974

ISU-ERI-AMES-75253
TCRL-3

DUCT FLOW ANALYSIS METHODS FOR V/STOL PROPULSION SYSTEM APPLICATIONS

Interim Report for the Period 1 July—30 September 1974

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December 1974

Approved for public release: distribution unlimited

Prepared for
Department of the Navy
Naval Air Systems Command
Code 310
Washington, D.C. 20361 USA

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ISU-ERI-74253	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DUCT FLOW ANALYSIS METHODS FOR V/STOL PROPULSION SYSTEM APPLICATIONS		5. TYPE OF REPORT & PERIOD COVERED Interim Report, 1 July to 30 September 1974
		6. PERFORMING ORG. REPORT NUMBER TCRL-3
7. AUTHOR(s) George K. Serovy and Patrick Kavanagh		8. CONTRACT OR GRANT NUMBER(s) N00019-74-C-0401
9. PERFORMING ORGANIZATION NAME AND ADDRESS Engineering Research Institute Iowa State University Ames, Iowa 50010		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 310A-018-4
11. CONTROLLING OFFICE NAME AND ADDRESS Department of the Navy Naval Air Systems Command, Code AIR-310 Washington, D.C. 20361		12. REPORT DATE December 1974
		13. NUMBER OF PAGES 24
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Propulsion
V/STOL Aircraft
Ducts
Fluid flow

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In this interim report a selected bibliography of recent journal articles concerned with V/STOL lift/thrust vectoring/propulsion systems and with potentially attractive internal flow field computation systems is presented and discussed. Many of the flow configurations associated with V/STOL propulsion are so complex, involving asymmetric cross-sections, severe bends, offset sections, diverters, bleeds, etc., that an investigation of the real role of computational fluid dynamics in design and analysis is indicated. A specific goal should be to gain a clear understanding of the current and

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) potential capabilities of candidate flow passage computational methods so that illusions can be destroyed and emphasis can be placed on the methods which can make a contribution now or at a predictable future time.

INTRODUCTION

The first Interim Report* for the current contract defined the segment of the overall V/STOL propulsion system problem to be considered during the remainder of the program. The general procedure to be followed was also outlined. It was indicated that the character of the flows in V/STOL propulsion configurations would be carefully investigated and that these flows would be examined in relation to the demonstrated as well as the potential capabilities of flow field computation methods.

The volume of documentation generated in even these restricted areas of study is overwhelming. However, it was and is believed that a significant sample of this literature should be reviewed and evaluated, and that the opinions and counsel of some of the sources of this literature should be obtained, both on an organizational level and on an individual basis. In the case of the literature it was decided that unclassified reports of United States and foreign government-funded research and development projects should be examined as well as the engineering and scientific journal and technical society papers published in directly-related fields.

In this interim report the arbitrarily made decision was to publish without detailed evaluation a grouped list of relevant <u>journal papers only</u>. There were a number of reasons for this choice, but a primary one is associated with the fundamental nature of journal publication. The first element of this reasoning is that the individual authors and organizational

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*Serovy, George K. and Kavanagh, Patrick. Duct Flow Analysis Methods for V/STOL Propulsion System Applications, Interim Report for the Period 1 April — 30 June 1974. Engineering Research Institute, Iowa State University. ISU-ERI-AMES-74167, TCRL-2. August 1974.

approvers considered the work of sufficient value and quality that they made the substantial effort required to prepare a manuscript. The second element is that the papers have generally passed through a competent and aggressive review process before publication or presentation. In this sense the list may be thought of as a pre-edited selection.

BIBLIOGRAPHY FOR DUCT FLOW ANALYSIS IN V/STOL APPLICATIONS

After an initial investigation of problem characteristics for duct flow application and integration in propulsion systems for V/STOL configurations, a bibliography (contained herein) of applicable technical information was drawn up. This bibliography, for which there were two primary objectives, namely, (1) requirements for high-lift augmentation devices, and (2) computational fluid dynamics for generalized three-dimensional duct analysis, is felt to be a reasonable coverage of the field over the last 4 or 5 years. The reviewing procedure followed has been to continuously supplement the material listed while at the same time acquiring reports and papers believed most pertinent or representative for actual review.

To organize the listing, divisions of general topics were assigned as follows:

- Propulsion System/Engine Integration Development
- General One-Dimensional and Empirical Duct Flow Analyses
- Computational Solution of the Multidimensional Navier-Stokes Equations
- Turbulent Flow Mechanics
- Two- and Three-Dimensional Flow, Transient and Secondary Flow Analyses
- Numerical Techniques for Differential Systems

The divisions and classes are the result of judgment of the authors with respect to striking a good compromise between completeness, compactness and relevance to duct flow analysis in V/STOL applications. Also, the inclusion of particular references in one division or another may be argued since subject matter may actually border one or more of the other divisions. Generally speaking, the most important divisions with regard to the stated objectives of the bibliography are the first four given in the list.

Computation fluid dynamics or numerical simulation of flow received its major impetus in the early 1960's with the work of Fromm and Harlow and the introduction of the latest generation of high-speed digital computers. The field has enjoyed great activity since that time in terms of development and refinement of basic modeling of fluid flow phenomena and numerical schemes for solution. It appears reasonable at this point to investigate whether or not computational fluid dynamics can play a real role in the design and detailed analysis of duct systems involving general arbitrary configurations with super-elliptic sections, severe bends, offset sections, diverters, side bleed holes, etc. Unfortunately, as Orszag and Israeli (1974) have pointed out, numerical simulation in fluid dynamics at this time remains an art. They state that in their view numerical experimentation should be the goal of computational fluid dynamics by which basic fluid-dynamical knowledge and physical insight into dynamics can be extended. This goal requires the thorough understanding of range of applicability of models used, and numerical coding which provides unquestioned flow-simulation results. Thus, to push computational fluid dynamics into exceedingly complicated flow problems with expectation of generating realistic flows for practical design application is extending the state of the art beyond present capabilities.

In design and development of high performance aircraft, optimum engine/airframe configuration and propulsion system integration pose essential problems. These problems are evidenced by the trends in thrust requirements, engine size and cycle characteristics. Accurate data are required on engine and airframe interaction, along with analytical methods to support integration trade-off studies. The external flow field to the aircraft and its resultant aerodynamic interactions with inlet and nozzle systems, and with the engines, are difficult to define, and even more difficult to evaluate.

Regarding high-lift systems for aircraft take-off and landing requirements, at least for conventional designs, mechanical flap systems at the wing leading and trailing edges have been successfully employed. Although lift coefficients of the order of 3 are achieved, boundary layer separation at larger flap deflections and angles of attack limit further increase. For V/STOL requirements, powered high-lift systems are therefore indicated, and these systems are accompanied by substantial increases in integration complexity in airframe and propulsion systems. One basis of approach to high-lift systems is the transfer of a portion of thrust kinetic energy by means of bleed or bypass air to large airflows around flap-extended wings of the aircraft. A number of concepts have evolved: external blowing of flaps, boundary layer control schemes, jet flaps, jet-augmentor wing and partial thrust vectoring by means of deflector systems. Direct methods of lift generation involve schemes such as wing fans, tilt wings, helicopter rotors, and others.

Although these approaches to airframe and propulsion system integration for V/STOL aircraft requirements are all primarily aerodynamic in nature, the related factors of stability and control, noise pollution, and economics of power high-lift will guide final evaluation of proposed concepts.

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CONCLUDING REMARKS

The preceding list is clear evidence of the tremendous effort being expended in technical activities related to a very limited component of applied research in propulsion system aerodynamics. It is equally clear that many if not most of the authors have no idea that they may be making a contribution to the eventual establishment of a sound basis for estimation of the performance of advanced V/STOL aircraft. A specific objective in the subsequent work on this program will be to point out those efforts which are making such a contribution and to define the requirements for additional contributions.

RESEARCH PLAN FOR FINAL INTERIM PERIOD

The remaining portion of the contract period will be devoted to the side-by-side evaluation of the flow situations and phenomena associated with lift/thrust vectoring/propulsion systems, and the currently and potentially available internal/external flow path analysis methods. The final report will deal with this evaluation and with future research and development programs of evident merit.